EVALUATION

A total of seven processes were tested at the Adams facility which included four first-stage processes, two second-stage processes, and one third-stage process. The processes were operated for a number of parameters. The processes are evaluated according to the stages and the process trains. Periods for evaluation of the individual processes and trains are grouped around dates on which significant events occurred. These events include the installation of the cylinder and cone in UASBR, change in methanol dosage rates for the process, change in phosphate dosage rate into feedwater, weather conditions, and start-up and operations of second and third-stage processes. The values in the summary tables are average values for the period that were collected or determined from data collected on a regular basis. Care should be taken when using the period average values for evaluation due to the number of data available for the period and may be heavily influenced by one data value.

First-stage Processes

The UASBR, UA2, FBR2 and PBR were the four first-stage processes tested at the facility. The primary purpose for the first-stage processes was to evaluate the processes and trains to reduce/remove selenium from agricultural drainage water. Since 85 to 95% of selenium in drainage water is in selenate (Se+6) state, selenium's most soluble form, the primary objective of a first-stage process was to reduce soluble selenium (selenate) to selenite (Se+4) or further to the particulate state (elemental). An ideal first-stage process would entirely remove all forms of selenium through volatilization.

To evaluate the processes on an equal basis (i.e., identical feedwater, operation of methanol dosing system, temperature, etc.), the periods used in the following tables were primarily based upon UASBR's Period 1 testing (two periods in Table 4), start of UA2 testing on June 1, 1994 , the phosphate dosage rate (changes on August 1, 1994 and August 29, 1995), installation of cylinder (June 1994) and cone (July 1995) in the UASBR, and flooding at the facility (March 1995). Dates for these significant events are listed in the Appendix of this report.

Table 4 compares percentage reduction of Sse that occurred in the first-stage processes. The highest reduction of soluble selenium occurred when the UASBR was initially put into operation using the bakery sludge in September 1992. Sse reduction was consistently above 80% for six weeks until December 7, 1992 with a retention time of 30 hours. The primary problem identified for this period and through the entire testing program was maintaining a uniform flow through the sludge bed. During this period, high upflow velocities (1.8 gpm/ft2) were used to elevate and mix the sludge bed, but in time proved inadequate. Mixing systems using various recycling schemes were instituted during all the periods of UASBR testing, but results varied.

As shown in Table 4, the UA2 demonstrated the best Sse reduction at the lowest retention time of all the first-stage processes for all periods except for the last one from September 2 through November 21, 1995. During this last 10-week period, both the PBR's and FBR's Sse reductions were higher at 65.4% and 64.9%, respectively, but the retention times were 3.4 and 2 times than that of the UA2. The FBR's retention time is based upon only the reactor volume and does not include the volume of the 100-gallon recycle tank.

Table 4
First-stage Processes
Reduction of Soluble Selenium and Retention Time

DATE		UASBR		UA2		FBR2		PBR	
From	To	Soluble Se Reduction %	Retention Time hours	Soluble Se Reduction %	Retention Time hours	Soluble Se Reduction %	Retention Time hours	Soluble Se Reduction %	Retention Time hours
10/26/92	12/07/92	80.8	29.9	-	-	-	-	-	-
12/07/92	03/09/93	58.0	29.9	-	-	-	-	-	-
02/02/94	05/31/94	58.6	9.6	-	-	66.8	3.7	25.7	6.5
06/01/94	06/23/94	65.1	9.6	80.1	3.6	73.4	3.7	74.5	6.5
07/13/94	08/01/94	56.8	5.2	75.0	3.6	66.9	3.7	43.9	6.5
08/02/94	02/15/95	36.1	5.2	47.7	2.1	35.4	3.7	34.7	6.5
03/27/95	07/07/95	45.1	7.6	63.5	1.9	44.3	4.0	60.4	6.5
07/10/95	08/29/95	48.8	9.1	53.9	1.9	32.0	4.0	74.5	6.5
09/02/95	11/21/95	52.7	10.3	52.7*	1.9	64.9	4.0	65.4	6.5
	Average**	47.0		55.4		49.2		48.8	

*

Period from 09/02/94 through 11/02/94
** Averages are weighted according to number of analyses per period

Table 5 shows the increase in alkalinity concentration along with the decrease in the pH value for all four first-stage processes. The values in the table are averages for the period. The increase in alkalinity is a result of the denitrification process. Alkalinity increases for the last period in Table 5 for all four processes were on par with the calculated increase of 198 mg/L as CaCO3 when using IC analyzed nitrate data (see Nitrate Analyses section) from August 1, 1995 through November 21, 1995.

Table 5
First-stage Processes
Change in Alkalinity and pH

From	To	Alkalinity	pH	Alkalinity	pH	Alkalinity	pH	Alkalinity	pH
10/26/92	12/07/92		na		na		na		na
12/07/92	03/09/93		na		na		na		na
02/02/94	05/31/94		-0.1		na		0.1		0.4
06/01/94	06/23/94		-0.1		0.1		0.1		0.2
07/13/94	08/01/94		0.1		0.1		0.1		0.0
08/02/94	12/19/94		-0.0		-0.1		0.2		2.0
12/20/94	02/15/95	112	-0.2	140	0.0	98	0.5	123	-0.1
03/27/95	07/07/95	138	-0.2	141	-0.1	71	0.2	151	0.0
07/10/95	08/29/95	140	-0.3	158	-0.4	71	0.0	172	-0.2
09/02/95	11/21/95	172	0.0	178	-0.5	159	-0.1	174	0.0

pH analyses began in March 1994
Alkalinity analyses began in December 1994
Alkalinity units are mg/L as $CaCO_3$. na is not available

Two summary tables for the first-stage processes are presented in Tables 6 and 7. Table 6 summarizes operation parameters of phosphate and methanol dosage rates, detention time and upflow velocity, average effluent dissolved oxygen and nitrate concentrations, and average nitrate and soluble selenium percent reduction values for periods of operation similar to those in Tables 4 and 5. Table 7 summarizes the effluent total, soluble and particulate selenium concentrations and percentage reduction of Tse and Sse and for each of the first-stage processes.

Table 6
First-stage Processes
Operation Parameters, Effluent Concentrations and Reduction of Nitrate and Soluble Selenium

Date From To	Phosphate Dosage mg/L as P	Methanol Dosage mg/L as methanol	Retention Time hours	Upflow Velocity gpm/ft2	Effluent D.Oxygen mg/l	Efluent Nitrate mg/L as N	Nitrate Reduced percent	Soluble Se Reduced percent
UASBR-Period 1								
10/17/92 - 03/08/93	0.05	349	29.9	1.821	1	1.3	94.4	66
UASBR-Period 3								
02/02/94 - 06/23/94	0.5	464	9.6	0.212	1	6.9	64.9	60.3
07/13/94 - 08/01/94	0.5	248	5.2	0.227	2.8	3.4	81.1	56.8
08/02/94 - 02/15/95	0.25	355	5.2	0.216	1.7	10	62.9	36.1
03/27/95 - 07/07/95	0.25	364	7.6	0.216	0.9	9.1	67.7	45.1
07/10/95 - 08/29/95	0.25	377	9.1	0.245	0.4	7.7	78.6	48.8
09/02/95 - 11/21/95	1.3	390	10.3	0.433	0.5	5	85.5	52.7
UA2								
06/01/94 - 08/01/94	0.5	319	3.6	0.234	0.6	6.8	77.7	77.9
08/02/94 - 08/14/94	0.25	304	3.6	0.202	0.6	4.1	84.6	66.3
08/15/94 - 03/09/95	0.25	336	2.1	0.442	0.7	10.3	62.9	46.2
04/01/95 - 08/29/95	0.25	340	1.9	0.386	0.4	6.1	81.1	60.2
09/02/95 - 11/02/95	1.3	400	1.9	0.4	0.5	3.9	87.9	52.7
FBR2								
10/21/93 - 12/17/97	0.5	147	0.82	30.7	2.3	21.5	21	12.5
12/31/93 - 08/01/94	0.5	282	3.7	36.5	1.1	3.1	88.4	62.1
08/02/94 - 01/10/95	0.25	260	3.7	51.3	0.8	8.4	68.5	32.5
02/03/95 - 03/09/95	0.25	287	3.7	60.4	0.7	13	60	66
04/01/95 - 09/01/95	0.25	279	4	63.5	0.5	7.4	77	40.2
09/02/95 - 11/21/95	1.3	284	4	42.4	0.5	3	91.2	64.9
PBR								
01/01/94 - 03/17/94	0.5	321	6.5	0.17	0.9	23.5	-0.3	24.3
03/18/94 - 08/01/94	0.25	218	6.5	0.17	1	4.7	81	56.2
08/02/94 - 03/09/95	0.25	260	6.5	0.17	0.8	16.3	40.7	32.8
04/01/95 - 08/29/95	0.25	271	6.5	0.17	0.5	4.5	86.1	65.5
09/16/95 - 11/21/95	1.3	264	6.5	0.17	0.6	2.6	92.3	65.4

*as methanol

Table 7
First-stage Processes
Effluent Selenium Concentrations and Selenium Reductions

Date From To	Effluent Total Se ug/L	Effluent Soluble Se ug/L	Effluent Part Se ug/L	Effluent Selenite ug/L	Total Se Reduced percent	Soluble Se Reduced percent
UASBR-Period 1						
10/26/93 - 03/08/93	379	168	211	23	27.2	66.0
UASBR - Period 3						
10/21/93 - 02/01/94	447	341	108	52	11.0	30.9
02/02/94 - 05/31/94	346	197	129	33	30.8	58.6
06/01/94 - 06/23/94	576	226	365	40	-9.0	58.8
07/13/94 - 08/01/94	739	199	540	36	-36.1	61.4
08/02/94 - 11/02/94	407	319	178	43	8.8	37.8
11/03/94 - 02/15/95	476	336	140	20	19.7	39.2
03/27/95 - 07/07/95	388	256	133	36	18.6	45.0
07/10/95 - 08/29/95	444	250	193	18	10.3	48.8
09/02/95 - 11/21/95	541	282	282	24	5.7	52.7
Weighted Average**	456	281	172	35	13.6	44.5
UA2						
06/01/94 - 06/23/94	354	111	263	9	35.4	79.0
07/13/94 - 08/01/94	665	114	551	31	-23.9	77.1
08/02/94 - 11/02/94	388	164	225	27	28.2	68.0
11/03/94 - 02/15/95	521	359	162	24	3.8	28.9
03/27/95 - 07/07/95	391	164	242	17	18.6	64.6
07/10/95 - 08/29/95	561	226	336	48	-15.1	53.9
09/02/95 - 11/01/95	492	268	223	29	11.7	51.9
Weighted Average**	470	223	248	26	10.2	55.5
FBR2						
10/21/93 - 02/01/94	431	400	45	44	23.0	26.4
02/02/94 - 05/31/94	331	155	191	30	27.2	67.3
06/01/94 - 06/23/94	323	141	182	20	39.2	73.3
07/13/94 - 08/01/94	288	171	116	67	46.9	66.9
08/02/94 - 11/02/94	469	321	147	46	20.9	43.3
11/03/94 - 02/15/95	475	362	113	38	15.7	31.5
03/27/95 - 07/07/95	332	277	55	50	35.5	44.3
07/10/95 - 08/29/95	378	335	44	6	23.2	32.0
09/02/95 - 11/21/95	299	212	87	22	49.5	64.9
Weighted Average**	382	275	109	36	28.7	44.7
PBR						
01/03/94 - 02/01/94	403	319	84	28	15.9	32.4
02/02/94 - 05/31/94	398	340	79	43	13.5	29.1
06/01/94 - 06/23/94	419	134	285	17	22.2	75.5
07/13/94 - 08/01/94	396	287	108	70	26.8	43.9
08/02/94 - 11/02/94	363	212	150	51	37.5	61.1
11/03/94 - 02/15/95	488	430	58	20	9.5	14.4
03/27/95 - 07/07/95	274	171	110	28	38.8	60.4
07/10/95 - 08/29/95	286	126	160	19	42.1	74.5
09/02/95 - 11/21/95	487	205	282	21	17.9	65.4
Weighted Average**	390	259	135	32	27.0	49.7

*All values are average for period
**Weighted average is for entire testing period

Second-stage Processes

FBR1 and SSF2 were the two second-stage processes tested at the Adams facility. Due to the nature of the processes and their position in the treatment train, their treatment objectives were different. With FBR1 being the second stage of a three-stage process, its objective was to further reduce selenium to an elemental or particulate state. Since SSF2 was the final stage of Treatment Train 2, its primary objective was to remove particulate selenium.

Table 8 provides a summary of operation parameters and resulting nitrate and soluble selenium reduction percentages for FBR1. The best SSe reduction of 51.1% was achieved at the end of testing from September through November 1995 when the reactor was operated at the longest retention time of 1.5 hours and occurred when the plant's feedwater phosphate dosage rate was 1.3 mg/L.

Table 8
Second-stage Processes
Operation Parameters and Nitrate
and Soluble Selenium Reduced

Date		Phosphate Dosage	Retention Time	Upflow Velocity	Average Effluent DO	Average Effluent Nitrate	Nitrate Reduced	Soluble Selenium Reduced
From	To	mg/L as P	hours	gpm/ft2	mg/L	mg/L as N	Percent	Percent
Fluidized Bed Reactor 1								
10/21/93	02/01/94	0.5	0.3	17.2	1.4	2.9	77.6	40.4
02/02/94	05/31/94	0.5	0.3	24	0.8	2	65.1	21.8
06/01/94	06/23/94	0.5	0.3	28.8	0.7	2.7	47.8	44.8
07/13/94	08/01/94	0.5	0.3	31.3	0.8	1.1	84.5	46.5
08/02/94	01/19/95	0.25	0.3	48	0.7	9.9	-6.2	5.3
01/20/95	02/13/95	0.25	0.6	72	10	16.2	-5.6	5.6
03/31/95	07/07/95	0.25	0.6	67	0.6	2.8	47.5	28.9
07/22/95	08/18/95	0.25	0.6	67	0.4	1.8	65.7	32.8
09/06/95	11/21/95	1.3	1.5	61.1	0.5	1.2	79.9	51.5
Slow Sand Filter 2								
11/08/93	02/01/94	0.5	1.5	na	1.1	4.9	60	31
02/02/94	05/31/94	0.5	1.5	na	0.7	3.1	*	47.4
06/01/94	06/23/94	0.5	1.5	na	0.6	3.1	*	37.1
07/13/94	08/01/94	0.5	1.5	na	0.6	21	22.5	-46.7
08/02/94	11/02/94	0.25	1.5	na	0.5	4.7	1.8	31.3

The other second-stage process, slow sand filter 2, was operated for a 1-year period from November 1993 to November 1994. The SSF2 was operated at feed flow rate of 0.5 gpm, which equates to a retention time (or empty bed contact time) of 1.5 hours. Table 9 is summary of the results for the second-stage processes and provides effluent selenium concentrations and percentages of selenium reduced. The negative % values in the table show that the constituent increased from the influent to the effluent concentration. As previously stated in the report, particulate selenium is the difference of soluble selenium from total selenium. For this report, it should be noted that in all calculations for Pse reduction and Pse concentration averages, Pse was taken to be 1 when the Pse value was 0 or a negative number.

Table 9
Second-stage Processes
Effluent Selenium Concentrations and
Percentages of Selenium Reductions

Date From To	Total. Selenium ug/L	Soluble Selenium ug/L	Particulate Selenium ug/L	Selenite ug/L	Total Se Reduced percemt	Soluble Se Reduced percent	Part. Se Reduced percent
FBR1							
10/21/93 - 02/01/94	444	207	237	51	3.9	39.7	-113.0
02/02/94 - 05/31/94	338	115	175	28	5.4	21.8	-38.9
06/01/94 - 06/23/94	452	95	340	23	2.0	44.8	-26.6
07/13/94 - 08/01/94	413	109	304	40	1.7	53.6	-112.0
08/02/94 - 11/02/94	469	272	198	89	4.9	18.6	-45.0
11/03/94 - 02/15/94	429	357	71	63	10.9	-9.0	51.9
03/27/95 - 07/07/95	263	182	82	67	30.5	26.3	34.1
07/10/95 - 08/29/95	296	157	139	14	31.1	35.5	23.1
09/02/95 - 11/21/95	339	127	212	30	33.6	51.5	-41.0
Weighted Average**	382	200	178	51	15.0	28.6	-21.7
SSF2							
11/08/93 - 02/01/94	311	230	90	65	30	31.0	13.9
02/02/94 - 05/31/94	187	100	87	40	46.9	47.4	21.7
06/01/94 - 06/23/94	198	109	78	9	48.0	37.1	63.7
07/13/94 - 08/01/94	552	297	52	29	83.8	53.1	9.8
08/02/94 - 11/02/94	309	233	78	85	40.9	31.3	8.0
Weighted Average**	279	182	95	56	37.6	32.3	18.6

*All values average for period
**Weighted average is for entire period

For FBR1, particulate selenium increased in six out of the nine analysis periods of Table 7. The lowest average total selenium concentrations of 263 ug/L and 296 ug/L occurred during two consecutive periods from March through September 1995 when the particulate selenium was reduced 34.1% and 23.1%. As for SSF1, the lowest effluent total selenium concentration averaged 187 ug/L and 198 ug/L for two consecutive periods that encompassed February through May 1994 and occurred when particulate removal was highest at 21.7% and 63.7%.

Third-stage Process

Slow sand filter 1 was the solitary third-stage process tested at the Adams facility. Testing with the SSF1 was identical to the SSF2's testing time frame from November 1993 to November 1994 and at identical operation parameters. A summary of effluent selenium concentrations and selenium reduction results for SSF1's operation is shown by Table 10. The effluent total selenium concentration averaged 195 ug/L from February through May 1994. During this period, additional selenium reduction occurred as evidenced by the 66.6% increase of Pse through the filter.

Table 10
Third-stage Process
Effluent Selenium Concentrations and
Percentages of Selenium Reductions

Date From To	Effluent Total Se ug/L	Effluent Solublel Se ug/L	Effluent Part. Se ug/L	Effluent Selenite ug/L	Total Se Reduced percent	Soluble Se Reduced percent	Part. Se Reduced percent	Selenite Reduced percent
SSF 1								
11/08/93 - 02/01/94	220	108	112	25	50.4	48.5	12.4	12.4
02/02/94 - 05/31/94	195	81	120	24	44.2	34.0	23.4	23.4
06/01/94 - 06/23/94	275	144	100	21	31.8	-62.6	57.8	57.8
07/13/94 - 08/01/94	301	68	233	37	29.7	36.2	32.2	32.2
08/02/94 - 11/02/94	254	199	53	84	45.0	8.7	35.0	35.0
Weighted Average**	236	132	102	46	45.1	15.9	24.1	24.1

*All values average for period
**Weighted average is for entire period

Process Trains 1 and 2

There were two process trains tested at the Adams facility. Process Train 1 consisted of the UASBR>FBR1>SSF1 and Train 2 was the UASBR>SSF2. Both trains were operated for approximately one year and ended on November 2, 1994 when testing the filtration process ceased. A summary of effluent selenium concentrations and selenium reduction results for both trains is shown by Table 11.

Table 11
Process Trains 1 and 2
Effluent Selenium Concentrations and
Percentages of Selenium Reductions

Date From To	Effluent Total Se ug/L	Effluent Soluble Se ug/L	Effluent Part. Se ug/L	Effluent Selenite ug/L	Total Se Reduced percent	Soluble Se Reduced percent
Process Train 1: UASBR>FBR1>SSF1						
11/08/93 - 02/01/94	220	108	112	25	57.5	78.8
02/02/94 - 05/31/94	196	81	120	24	61.4	83.4
06/01/94 - 06/23/94	281	143	98	23	46.6	64.1
07/13/94 - 08/01/94	301	68	233	37	44.5	86.8
08/02/94 - 11/02/94	254	199	53	84	53.2	60.8
Weighted Average**	235	133	102	46	56.6	73.3
Process Train 2: UASBR>SSF2						
11/08/93 - 02/01/94	311	230	90	65	44.2	58.5
02/02/94 - 05/31/94	187	100	87	40	66.1	80.9
06/01/94 - 06/23/94	189	106	70	9	63.4	76.7
07/13/94 - 08/01/94	552	297	255	47	-3.1	41.3
08/02/94 - 11/02/94	309	233	78	85	43.1	53.9
Weighted Average**	279	182	95	56	49.2	64.5

*All values average for period.
**Weighted average is for entire period.

For the overall operation, Train 1 had marginally better results than Train 2. Overall, Tse and Sse reductions for Train 1 were 56.6% and 73.3%, respectively, while the Tse and Sse reductions for Train 2 were 49.2% and 64.4%, respectively.